

1995127371

**FOR GEOLOGIC INVESTIGATIONS WITH AIRBORNE THERMAL
INFRARED MULTISPECTRAL IMAGES: TRANSFER OF CALIBRATION
FROM LABORATORY SPECTROMETER TO TIMS AS ALTERNATIVE FOR
REMOVING ATMOSPHERIC EFFECTS**

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1. INTRODUCTION

This paper describes an empirical method to correct TIMS data for atmospheric effects by transferring calibration from a laboratory thermal emission spectrometer to the TIMS multispectral image. The method does so by comparing the laboratory spectra of samples gathered in the field with TIMS 6-point spectra for pixels at the location of field sampling sites. The transference of calibration also makes it possible to use spectra from the laboratory as endmembers in unmixing studies of TIMS data.

2. THE PROBLEM

The emissivity and spectral unmixing study described in this volume by Edgett *et al.* (1995) was designed to use a TIMS image (obtained September 1991) to address the geology of a dune field in Christmas Lake Valley, Oregon. In that study, accurate determination of surface temperature was not required. However, Edgett *et al.* (1995) desired to obtain accurate estimates of surface emissivity, a property directly related to the composition of surface materials. To obtain surface emissivity, the effects of atmospheric contributions (including H₂O vapor in TIMS band 1 and O₃ in band 4) to the TIMS spectrum had to be removed.

Atmospheric correction for TIMS images usually involves the use of a radiative transfer code such as the Lowtran 6 or Lowtran 7 atmospheric models developed for the U.S. Air Force (*e.g.*, see Hook *et al.*, 1994). The Lowtran code uses an input or modeled atmospheric profile. An input profile might include pressure, temperature, and humidity as a function of altitude measured at the time of the TIMS overflight. In the case of most TIMS flights (including that of September 1991 over Christmas Lake Valley), these parameters are usually not measured and a model atmosphere must be assumed. The best model atmosphere that can be assumed by Lowtran for a mid-September overflight in Oregon is for "North American mid-latitude Summer." However, it was found in the Edgett *et al.* (1995) study that the model atmosphere over-predicted the humidity in arid Christmas Lake Valley, Oregon, resulting in radiances for TIMS band 1 that were inordinately higher than in the other five bands. The artificially high radiance in band 1 off-set the emissivities calculated (using the method of Realmuto (1990)) for all six bands, because the surface kinetic temperature is assumed to be the same as that detected by the band with the highest radiance. The main problem that resulted was that band 1 emissivities were exceptionally high relative to the other TIMS bands and to what was observed in laboratory spectra of samples collected from sand dunes located in the TIMS scene (*e.g.*, Figure 1). The problem was the same for spectra of water and vegetation, which should have had relatively flat spectra.

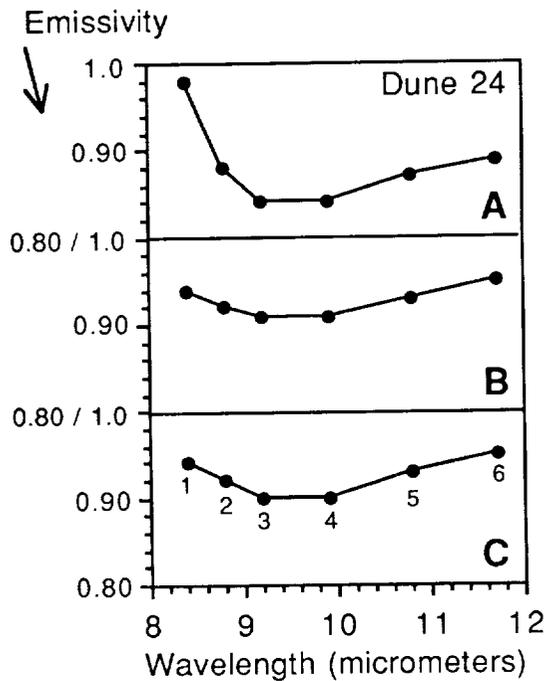


Figure 1. Comparison of six-point emissivity spectra of sand near the crest of one of the dunes in the Shifting Sand Dunes field of Christmas Lake Valley, Oregon (see Edgett *et al.*, 1995). Band 1 through 6 of a TIMS image obtained in September 1991 are indicated. (A) Spectrum from TIMS image using Lowtran atmospheric correction. (B) Spectrum from TIMS image after empirical correction as described here. (C) Laboratory spectrum convolved to TIMS spectral resolution. Note the inordinately high emissivity in band 1 for the Lowtran-corrected spectrum.

3. PROPOSED SOLUTION

When the relative humidity is not known, the atmosphere correction for water vapor can be solved by assuming a different humidity, as suggested by Hook *et al.* (1994). Alternatively, atmospheric effects can be corrected empirically by calibrating the TIMS image to a known surface spectrum, such as a body of water, vegetation, or the spectrum of material collected from the field area. For example, Ondrusek *et al.* (1993) used snow in a TIMS scene to calibrate an image. This approach precludes the need for a radiative transfer code, and therefore might not be easily applied to all thermal infrared images of remote or inaccessible areas, particularly if seen from very high altitudes. However, this alternative approach was used because of (1) the emphasis on surface geology and (2) the difficulty in application of the Lowtran atmospheric model to the Christmas Lake Valley TIMS image of Edgett *et al.* (1995).

Conceptually, the approach followed here is a model for transfer of calibration from the laboratory spectrometer to the TIMS. More sophisticated examples of laboratory spectrometer calibration transfer models are found in papers by Adhietty *et al.* (1991) and Wang and Kowalski (1992). The philosophical justification for this approach is that the atmospheric column during acquisition of laboratory spectra has a very short path length (< 1 m) relative to that of the TIMS in an aircraft (> 3,000 m), and water vapor (humidity) in the laboratory setting is minimal.

Transference of calibration from the laboratory spectrometer data to the TIMS emissivity image requires two main steps. The first is to obtain laboratory spectra of materials that occur within the scene and convolve to TIMS six-band resolution. The second step is to calibrate the TIMS normalized emittance image using the average of several (in this case, 10) of the laboratory spectra and then check the calibration transfer using several other laboratory spectra (here, another 10 were used). The steps followed are described in more detail below.

4. SPECIFIC STEPS

4.1 Laboratory Spectra of Christmas Lake Valley Samples

Laboratory thermal emission spectra of sand samples from the Shifting Sand Dunes of Christmas Lake Valley, Oregon, were obtained, convolved to TIMS six-band resolution, and used in the empirical correction for atmospheric effects (see section 4.2, below). The configuration and calibration of the laboratory thermal emission spectrometer at Arizona State University was described by Christensen and Harrison (1993) and in a manuscript presently being prepared by S.W. Ruff, P.W. Barbera, P.R. Christensen, and D.L. Anderson. Laboratory thermal emission spectra were acquired for this study using a commercial fast Fourier transform infrared spectrometer (Mattson Cygnus, modified for emission measurements) with a spectral resolution of 4 cm^{-1} . Atmospheric contributions to spectra from water and CO_2 are minimized by using a dry nitrogen purge and cold finger to trap excess water. Emission spectra were obtained according to "method 1" of Christensen and Harrison (1993).

Laboratory spectra were collected for 25 bulk sediment samples from the Shifting Sand Dunes. The samples were subsequently impregnated with epoxy and cut for thin section analysis. Twenty of the spectra obtained from the laboratory were used in the procedure for transferring calibration from laboratory data to the TIMS image of the dunes obtained in September 1991. The sand samples contain mostly plagioclase feldspar, volcanic glass, ash aggregates, basalt lithic fragments, pyroxenes, and magnetite/opaque minerals (Edgett, 1994).

4.2 Empirical Transfer of Calibration to TIMS

The empirical corrections for the 1991 TIMS image of the Shifting Sand Dunes of Christmas Lake Valley (see Edgett *et al.*, 1995) involved the following steps:

(1) Normalized emittance (Realmuto, 1990) was derived from the radiance image calibrated to the two onboard blackbodies.

(2) The emittance image was corrected for atmospheric attenuation effects on the sides of the TIMS scan. These effects are caused by the side-scanning nature of TIMS, thus there is more atmosphere between the instrument and surface as a function of angle away from nadir. A low pass filter (1 line by 211 samples) was used to remove high-frequency features. The resulting image was a map of low frequency brightness (in this case, emittance) variations across the image. The image was darker in the middle and brighter on the sides, consistent with increased atmospheric attenuation on the sides of the scan. The average of this brightness variation was then subtracted from the original emittance image, and the result of this step was re-boosted to have the same slope and offset (DN stretch) as the original emittance image.

(3) The average of ten laboratory spectra (convolved to TIMS wavelengths) of samples collected from the field area were compared to the average six-point spectra of the image pixel corresponding to the location where each of the field samples was collected. The average difference between the two data sets were used to correct the emissivity image for atmospheric effects by essentially forcing a transfer of calibration from laboratory to TIMS image. In this case, the average difference in emissivity between the laboratory spectra and TIMS emittance image was 0.007 (bands 1, 2, 5) to 0.027 (band 6).

(4) The newly calibrated and corrected image was checked by comparing ten different (than used in step 3) laboratory spectra to the TIMS image. Again, laboratory spectra are convolved to TIMS six-point resolution and compared with the image emissivity for the pixel corresponding to the site where a sample was collected. The

difference between the two should be small. In this case, differences ≤ 0.01 emissivity were considered to be successful, and the average differences were only 0.001 to 0.003.

5. DISCUSSION AND CONCLUSIONS

In an ideal situation, the spectra used in steps 3 and 4 above should be very different from those of the material of interest in the study. They should also be different from each other (for example, if spectra used in step 3 were for quartzite outcrops and spectra in step 4 were for basalt flows). However, most spectra of samples collected in the vicinity of the Shifting Sand Dunes of Christmas Lake Valley are very similar. There are no outcrops of material composed of something completely different (e.g., quartz-rich rock) relative to the dune sand. All of the geologic materials are glassy volcanics (Edgett, 1994). The spectra that are different from the dune sand are those of materials that typically have relatively flat spectra, like vegetation and fine-grained playa surfaces. The results for step 4 above were compared with the laboratory spectrum of playa salts and indeed found to be flat.

The approach used here to remove atmosphere from a TIMS image appears to be a very promising method for work with airborne thermal infrared images used for geological purposes. The advantage of this approach is that now laboratory spectra can be applied to unmixing analysis of the image. Use of laboratory spectra for mixing analysis means that spectral libraries might be applied with relative ease. Use of laboratory spectra to unmix the September 1991 Shifting Sand Dunes image is a goal of future work (Edgett *et al.*, 1995). Before this is done, however, it will be necessary to further test the empirical atmospheric correction approach by using a different TIMS scene that has surfaces of widely contrasting composition, such as the Kelso - Cima, California image described by Barbera (1989).

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